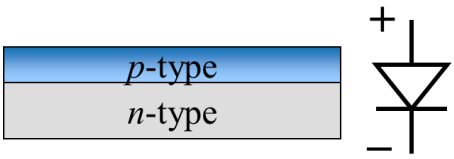
Report due 10/16/20 by the end of day



Exploring PN Junction Diode

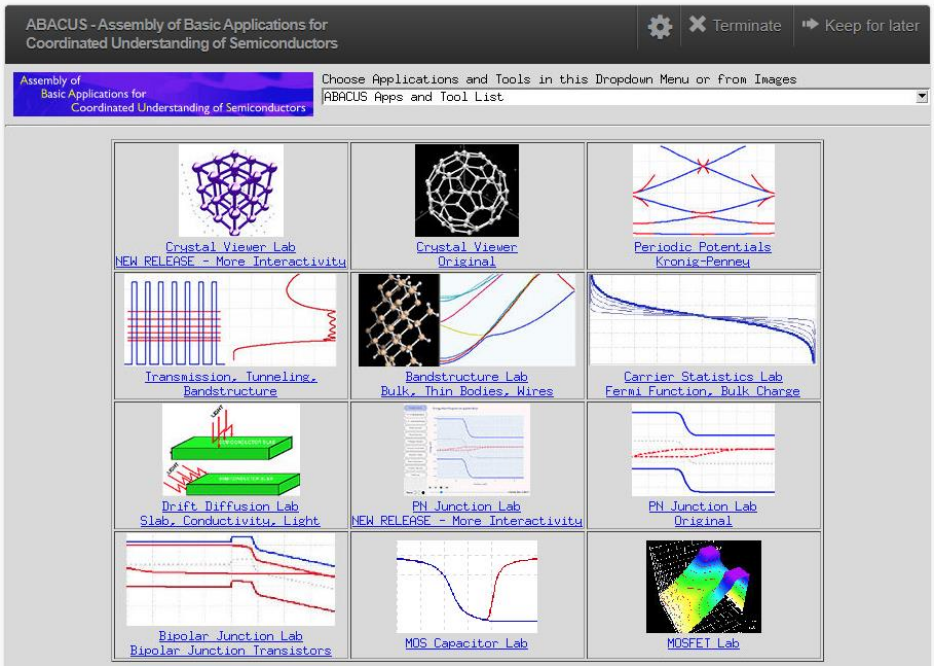
Project Goal:

Your task in this laboratory project to explore and understand operation of PN junction diodes and gain insight into some limitation associated with a simplified the textbook model. The simulation tool is available at Nanohub. (nanohub.org).

We have discussed in class the depletion approximation. The depletion approximation is extremely useful, when it is valid, so it is important to understand its limitations. In this work, you will compare the results of depletion approximation analyses of PN junctions with the "exact" solution obtained by solving the semiconductor equations directly by numerical simulation using the computer program.
The lab will include your calculation of PN junction characteristics based on depletion approximation and simulation of PN junction diode characteristics using Nanohub.

Nanoub Tutorial:

1. Go to www.nanohub.org
2. Hit the menu tab at the top right of the screen.
3. Log in to the website.
4. On the top of the page, click the Resources tab.
5. Now click on "Tools"
6. On the next page, you'll see "Tag", "Resources", and then "Info" each horizontally adjacent.
    a. Under "Tag" click "[All]"
    b. Under "Resources", click "ABACUS…"
    c. Under "Info", hit "Launch Tool"
7. Here, you will see this screen, which we will go to before all labs:



8. Make sure to click on "PN junction lab"

By the end, you should:

- Know how to calculate idealized characteristics of PN junction diodes using the depletion approximation
- Know how to use NanoHub PN junction lab to band structure, electric field as a function of applied bias, charge distribution, and IV characteristics of PN junction diodes.
- Understand the relation between PN junction design and its forward-bias characteristics, including electric field, charge distribution, and IV characteristics.
- Understand limitations of the depletion approximation and relate them to nonidealities in PN junction IV characteristics

Project Actions:

Part 1: Analytical calculations with the depletion approximation:

1) A Si step junction maintained at room temperature under equilibrium conditions has a p-side doping density of $N_A = 2 \times 10^{15}/\text{cm}^3$ and an n-side doping of $N_D = 10^{15}/\text{cm}^3$.
Use the depletion approximation to compute:
(a) V_{bi}
(b) The depletion layer boundaries, x_p, x_n, and the depletion width, W
(c) The electric field at the junction.
(d) The electrostatic potential at the junction.
(e) Plot of the charge density, electric field, and electrostatic potential as a function of position, as well as I-V characteristics.

2) Repeat problem 1), still using the depletion approximation, but set the p-side doping to $N_A = 3 \times 10^{17}/\text{cm}^3$ and keep the n-side doping at $N_D = 10^{16}/\text{cm}^3$. Compute the same quantities as in problem 1) and compare the results to those of problem 1).

Part 2: "Exact" numerical simulations and their comparison with "textbook" result:

Set the doping densities on the P and N sides of the junction to correspond to those in problem 1) above.

Set the length of the P-region to be 1.0 micrometer and for the N-region, 2.0 micrometers. Be sure that you have selected "Si" as the material and that the temperature is "300K."

Simulate the parameters of the defined structure .

3a) Use the potential vs. position plot to determine the built-in potential of the PN junction. Compare your answer to the depletion approximation result. (Remember that potentials always have an arbitrary reference, so don't be confused by the fact that the potential is not zero on one side of the junction.)

3b) Use the carrier density vs. position plot to estimate the width of the depletion layers on the P and N sides, x_p and x_n. First, plot side-by-side the carrier density vs. position assumed in the depletion approximation and the numerically generated plot, then determine whether the depletion approximation results are reasonable. Explain.

HINT: Use appropriate axes for the plot. The vertical and horizontal axes should be linear with appropriate minimum and maximum limits so that you can resolve the profiles.

3d) On the electric field vs. position plot, sketch the depletion approximation result and discuss the differences.

3e) For the charge density vs. position plot, plot side-by-side numerical data and the corresponding depletion approximation result. You will need to use appropriate axes for the plot.

3f) Plot forward-bias IV characteristics obtained from the numerical simulations and compare them with the ideal IV obtained using the depletion approximation. To resolve the details of IV plot, use semi-logarithmic plot for the vertical (current) axis.

4) Set $N_A = 3 \times 10^{17}/cm^3$ and $N_D = 10^{16}/cm^3$, and rerun the simulation.

4a) Compare the depletion approximation results to the simulated built-in potential, V_{bi}, depletion layer boundaries, x_p, x_n, depletion width, W, and electric field at the junction.

4b) On the electric field vs. position plot, superimpose the depletion approximation result and discuss the differences.

4c) On the carrier density vs. position plot, superimpose the depletion approximation result and discuss the differences.

4d) On the charge density vs. position plot, superimpose the depletion approximation result and discuss the differences.

4e) Compare the analytical and numerically simulated IVs.

Compare the simulation and analytical results. When comparing the numerical and analytical results, copy the numerical results from Nanohub and sketch/plot the analytical results on the same page for side-by-side comparison.

Report Format:

This report should have continuous flow without any breaks or abrupt transitions! Everything included in the report must serve a purpose! The report must reflect specifically what you learned in this lab project. Use sections such as **Introduction, Methods, Results and Discussion, and Conclusions**.

Figures (schematics, simulation screenshots, etc.), tables, and equations (e.g. Fig. 1, Table 1, Eqn. 1) must be consecutively numbered in the order they appear and must be properly cited in the text of the report (e.g. as shown in Fig. 2 …, Table 1 tabulates …, According to Eqn. 3 …). All figures and tables must have captions.

References must be provided at the end of the document and all references must be cited properly within the text. (Wikipedia is not acceptable)

Failure to satisfy these requirements will result in a lower grade.

Report Deliverables:

Introduction should overview the basics of PN junction devices including major features of their design and typical applications.

For part 1, compile the results of your calculations:

List the equations used with a legible description of their purpose, specification of parameters, and values of physical constants used (e.g. Boltzmann constant).
You are encouraged to use computer software for the calculations, when it is justified and possible.

For part 2, compile all the relevant the relevant simulation results: charge density, electric field, and electrostatic potential as a function of position

Using the resulting plots, answer the following questions.

For the symmetrical (or nearly symmetrical) PN junction, problem 3 shows that the depletion approximation works well, except for some small differences. For the asymmetrical PN junction, however, the depletion approximation produces significant errors for the charge density and electric field. Use the plots to explain why

the depletion approximation fails for asymmetrical junctions. Why the depletion approximation breaks down so obviously for the asymmetrical PN junction?

HINT: To answer this question, it is useful to examine the energy band diagrams, the carrier density plots, and the charge density plot.